GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: August 14, 1978

Project Title: Millimeter Terminal Homing Proposal

Project No: A-2165

Project Director: Mr. J. A. Scheer

Sponsor: General Electric Company, Aerospace Electronic Systems Dept; Utica, N.Y. 13503

Agreement Period: From 5/22/78 Until 9/1/78 (Contract Expiration)

Type Agreement: Purchase Order No. F12-9F-02642 (Government Subcontract)

Amount: $9,940 (Fixed-Price)

Reports Required: Final Technical Letter Report

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Defense Priority Rating: None

Assigned to: Radar Instrumentation Laboratory (School/Laboratory)

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GEORGIA INSTITUTE OF TECHNOLOGY
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SPONSORED PROJECT TERMINATION

Or
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Date: 12/4/78

Project Title: Millimeter Terminal Homing Proposal

Project No: A-2165

Project Director: Mr. J. A. Scheer

Sponsor: General Electric Company, Aerospace Electronic Systems Dept.; Utica, NY 13503

Effective Termination Date: 9/1/78 (Final Tech. Letter Report due date.)

Clearance of Accounting Charges: N/A - Fixed Price Subcontract.

Fixed Price
No cert. nec.

Grant/Contract Closeout Actions Remaining:

_ Final Invoice and Closing Documents

_ Final Fiscal Report

_ Final Report of Inventions

_ Govt. Property Inventory & Related Certificate

_ Classified Material Certificate

X Other Two (2) records/archives copies of Final Tech. Letter to OCA/SSD.

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Statement of Work and Schedule

The tasks involved in developing the sensor fall into one of two main catagories - sensor system design and development, and antenna system design and development. Each of these major tasks begins with a preliminary design phase, through which the long lead items are identified, follwed by a detail design phase. System development includes procurement of parts and materials, fabrication of the system and shake down and final testing.

Georgia Tech will also develop the radome to be used the the 95 GHz sensor.

Instrumentation Sensor

System Design Overview

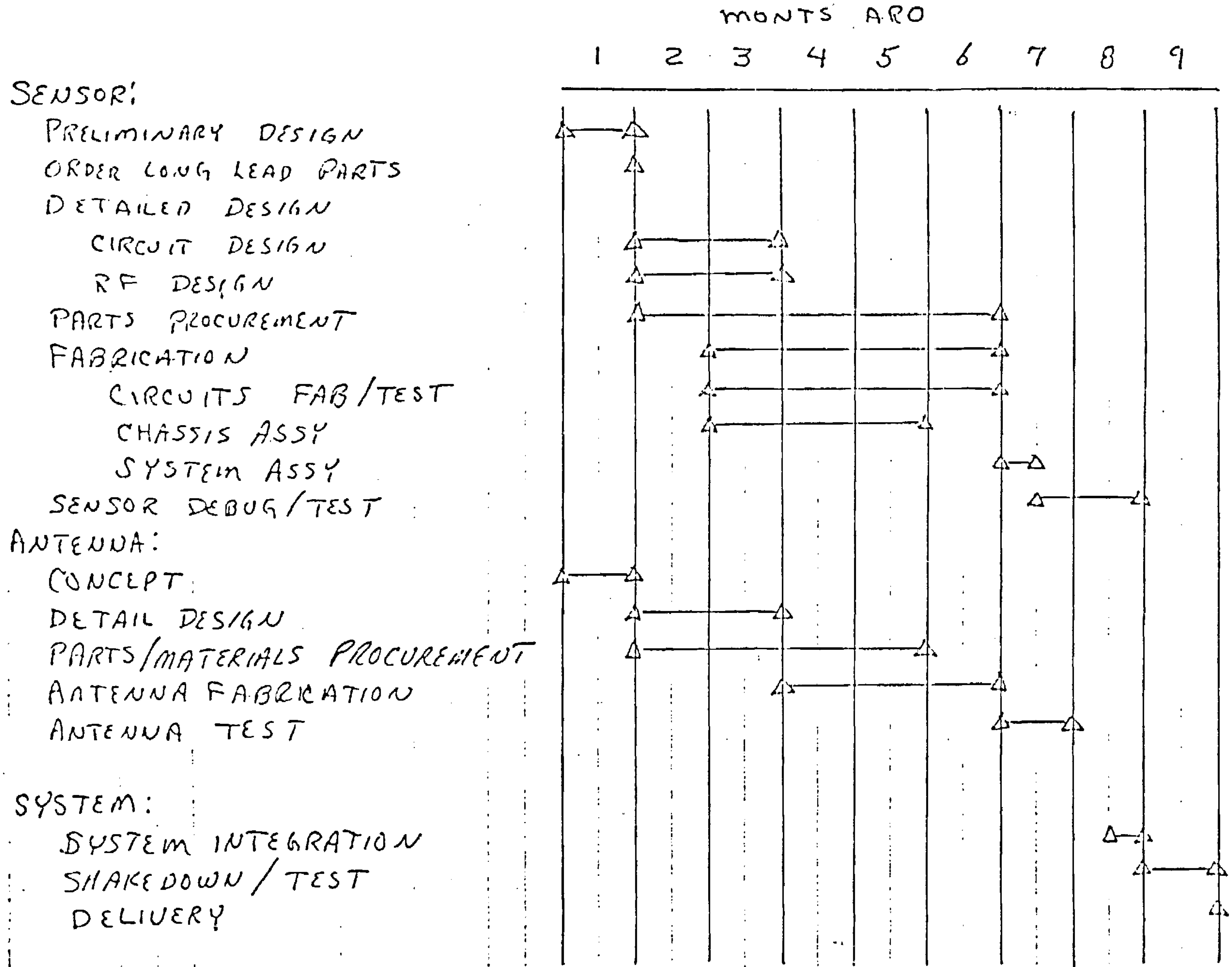
The instrumentation sensor is a 95 GHz radar transmitter/receiver set which, when the transmitter is not on, performs as a radiometer. The system employs a simultaneous lobing tracking technique (monopulse tracking) which operates in both the active (radar) and passive (radiometric) modes. The antenna system has the capability to incorporate a conical scanning mode if so desired in a future procurement.

The antenna system is one which allows selection fo three apertures; one providing a one degree (1°) pencil beam, one providing a three degree (3°) pencil beam, and one providing a one degree by ten degree ($1^{\circ} \times 10^{\circ}$) fan beam. Both pencile beams employ a four lobe monopulse beam pattern. The beams all have vertical polarization in this procurement, but the design is expandable to horizontal polarization as a future growth feature.

Transmitter

The transmitting source is an Impatt diode source operating nominally at 94.5 GHz. The peak power provided at the output is at least 5 watts, with a predetermined pulse length of 100 nanoseconds. The source frequency is swept over an r.f. frequency range of 250 MHz during the transmitted pulse. The center frequency of the transmitter source is predictable and stable to ± 5 MHz after a 5 minute warmup period.

The modulator/waveform generator circuitry provides the appropriate bias current and pulse current to the Impatt. The modulator/waveform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SENSOR:
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ORDER LONG LEAD PARTS
DETAILED DESIGN
CIRCUIT DESIGN
RF DESIGN
PARTS PROCUREMENT
FABRICATION
CIRCUITS FAB/TEST
CHASSIS ASSY
SYSTEM ASSY
SENSOR DEBUG/TEST
ANTENNA:
CONCEPT
DETAIL DESIGN
PARTS/MATERIALS PROCUREMENT
ANTENNA FABRICATION
ANTENNA TEST
SYSTEM:
SYSTEM INTEGRATION
SHAKEDOWN/TEST
DELIVERY

SCHEDULE

generator requires +70 volts D.C. and _28 volts D.C. power, and a 5 volt trigger pulse which "tells" the modulator when to develop the transmit current pulse.

A three port circulator is used to inject the transmitted pulse into the sum channel microwave path, providing 20 dB of isolation to the receiver, and about 1 dB of attenuation in the transmit path. Selection of antennas (fan beam or multihorn monopulse beam) for the r.f. energy is done by means of the solenoid actuated waveguide switch in the sum channel. This switch is responsible for an additional 0.5 dB attenuation in the sum channel.

Receiver

The system employs a three (3) channel receiver; a sum (Σ) channel (having a selectable linear or logarithmic response); an elevation difference (ΔEl) channel, providing an elevation error signal; and an azimuth difference (ΔAz) channel, providing an azimuth error signal. Each channel employs a Dicke switch operating mode for the purpose of calibrating the radiometer sensitivity. This feature is implemented using a switchable circulator at the input to each mixer which is capable of switching times less than a microsecond. This switchable circulator switches the preamp input between a temperature controlled load and the scene, as received by the antenna. With proper timing and control this switch also provides additional protection for the sum channel mixer during transmit time in the radar mode.

Integrated mixer/preamplifiers are used in each channel. The balanced mixer, in conjunction with the 500 to 1000 MHz r.f. preamps provide a 7.5 dB noise figure (dsB).

The local oscillator is a 20 milliwatt Gunn diode source, which is coupled to each mixer through an isolator to prevent cross-talk. The variable phase shifters in the delta channels are used to balance the phase with the sum channel. The sum channel has a solenoid actuated waveguide switch, which when activated inserts a 90° phase shift into that channel. This is used for calibration purposes. Including the losses in the isolators and in the phase shifters, approximately 5 milliwatts is injected into each mixer, which is the recommended power level for minimum noise figure. The frequency of the local oscillator is selected at 750 MHz below the transmitter frequency. Long term stability of the l.o. frequency is within 6 MHz, and only initial mechanical tuning is required to achieve the proper frequency; there is no need for an automatic frequency control loop. The sum channel employs a motor controlled step attenuator at i.f. to provide the capability for remotely calibrating the amplitude response of that channel. The calibration procedure involves boresighting the antenna on a known corner reflector at a known range, and inserting attenuation in 10 dB increments from 0 dB to 60 dB while recording the amplitude of the sum channel.

Each channel uses a linear i.f. post amplitifer to provide sufficient drive power for the phase detectors. The reference for each phase detector is the limited sum channel, and the ΔEl and ΔAz i.f. signals supply the other input to the elevation error and azimuth error phase detectors respectively. Each phase detector provides the in phase (I) and quadriture (Q) components of the phase signal, to provide signal processing adaptability and growth potential.

The sum channel has, in addition to the linear i.f. amplifier, a log i.f. amplifier to provide log video. This signal provides increased dynamic range capability for the amplitude response.

Each video signal, Az error, El error, linear Σ, and log Σ, has a video amplifier to provide the proper signal impedance and level for the high speed A/D converter.

The linera i.f. amplifiers have their gain controlled by means of the AGC loop which involves a control command which is fed back from the computer. This feature insures that the signal from the target being tracked is at an optimum level for tracking loop gain considerations. When the computer feed back signal for the AGC is not used, the AGC loop is closed within the radar. The range gate is manually positioned on the target of interest if the computer is not being used.

It is important to note that the tracking logic is different for radiometric tracking than it is for radar tracking, since for the radar mode normally tracking is done against a high reflectivity target and in the radiometric mode, tracking is normally done against a cooler or low emissivity target.

Calculation Of Signal to Noise Ratio

Radar Mode

The single pulse signal to noise ratio can be expressed as,

$$S/N = \frac{P_t \ G^2 \lambda^2 \sigma L_s}{(4\pi)^3 R^4 KT B_n F_n}$$

where

P_t =	transmitter power	=	5.0 watts
G =	Antenna Gain (9", 75% η)	=	38905
λ =	wavelength	=	3.2×10^{-3} meters
σ =	radar ~~constant~~ cross section	=	$30 \, m^2$
L_s =	system losses	=	12.8 dB
R =	range	=	1×10^3 meters
K =	Boltzmann's constant	=	1.38×10^{-23} J°K^{-1}
T =	reference temperature	=	290°K
B_n =	receiver noise bandwidth $(500 \times 10^6 \times 10 \times 10^6)^{1/2}$	=	50×10^6 Hz
F_n =	Mixer noise figure	=	11.0 dB

This results in a S/N ratio of

S/N = 13.8 dB

Radiometer Mode

The minimum detectable signal level for the radiometer (ΔT_{min}) is defined as

$$\Delta T_{MIN} = \frac{K(F-1)T_0}{\sqrt{\beta \tau}}$$

where

K =	receiver constant	=	2
F =	Noise figure + losses (6.3dB + 8.cdB)	=	26.9
T_0 =	Reference temperature	=	290°K
β =	IF Bandwidth	=	500×10^6 Hz
τ =	Integration time	=	0.1 sec

which produces a

$$\Delta T_{min} = 2.13°K$$

The target temperature area product is defined as

$$\Delta T_t A_t = \frac{\Delta T_A A_b}{C} \quad \text{or} \quad \Delta T_A = \frac{\Delta T_t A_t C}{A_b}$$

where

$\Delta T_t A_t$ =	Target temperature area product	=	1000 m^2K
ΔT_A =	apparent temperature change due to presence of target		
A_b =	Area beam normal to the line of sight at target range, for main beam (θ_{null} = 1.3°)	=	36.4 m^2
C =	main beam efficiency	=	0.95

and for the system produces a

$$\Delta T_A = \cancel{} \; 26.1\ ^\circ K$$

The signal to noise ratio for the target case can now be stated as,

$$\frac{\Delta Ta}{\Delta T_{min}} = \frac{26.1}{2.13} = 10.9 db$$

Timing and Control Unit

The timing and control unit (TCU) generates all of the timing signals required for operation of the sensor, based on commands generated either by the system computer or by manual control The TCU provides all interface timing to the system computer when it is in used.

The controls available on the control panel are:

Mode:	Off/Stby/Radiometer/Radar
PRF:	10-300 Hz
Control:	Manual/Computer
Antenna:	$1^o/3^o$/Fan Beam
Σ Amplitude:	Log/Linear
Calibrate:	0,10,20,30,40,50,60 dB

The signals required to be provided to the radar are:

Transmit trigger timing
Antenna selection command
Fan beam command
Dicke switch mode signal
Variable attenuator motor drive command
Radar/radiometer mode command
Σ video selection command

The signal required to be provided to the computer are:

A/D converter clock
Clock pulses to buffer (write)
Clock pulses to buffer (read)
Transmit sample time
PRF square wave
PRF square wave quadriture
Serial data -mode encoded
Radar mode -off/stby/radiometer/radar
Antenna selection status

Inputs required to the TCU from the computer are:

PRF Command

PRF Actual

PRF Mode Command

ANTENNA CONCEPT

Introduction

The proposed antenna concept for the millimeter terminal homing study sensor utilizes dielectric lens and elements to achieve beam formation with very low sidelobes. Georgia Tech has developed a number of such lens antennas for both monopulse and pencil beams at frequencies between 35 and 200 GHz for both radar and radiometer applications.

To achieve monopulse (simultaneous lobing) capability, a multi-horn lens feed will be used. The horn elements are to be located in the focal region of the lenses. The outputs of the horns are combined in RF hybrids to achieve three signals necessary for target illumination and tracking. The first antenna feed port (referred to as the sum or Σ) develops a pencil beam antenna used to illuminate the target and for gain referencing in the angle tracking receiver. The second and third antenna feed ports (referred to as the pitch and yaw differences, Δ_p and Δ_y) develop antenna patterns having a null on the tracker boresight axis. The phase relationship between Σ and Δ_p and Δ_y varies by 180° when the target crosses the boresight axis permitting complete up-down and right-left directional information to be developed in a circular zone of a size roughly that of the Σ pencil beam half power beamwidth.

Three significant advantages are obtained through the use of the sum and difference form of monopulse:

1. A boresighted pencil beam is available for target illumination in the active mode.
2. By forming the sum and difference signals directly at the RF (i.e., at 95 GHz), a significant reduction in the gain and phase stability of the down converter and IF amplifier is permitted.
3. Only three mixer/IF amplifier channels are required. (Instead of four if amplitude comparison monopulse was used.)

Pencil Beam/Monopulse Elements

Several aspects of the antenna requirements were considered in developing a suitable antenna concept. Briefly, the critical requirements are:

1. Selectable pencil beam half power beamwidths of 1° or 3°.
2. Simultaneous lobing capability.
3. Growth to dual polarization.
4. Operation from 94 to 95 GHz.
5. Growth to conical scan mode.

A number of methods of achieving the variable half power beamwidths were examined. Considered were different size apertures, variable amplitude illumination of the aperture and variable phase illumination of the aperture. The best approach is one requiring the fewest moving elements and one capable of lowest RF loss. Figures 1 and 2 show the selected concept. Here a 9-inch diameter dielectric lens is used. The lens is illuminated by a multi-horn feed located in the focal zone of the lens. When properly focused the 9-inch aperture will produce a 1° half power beamwidth pencil beam. When defocused such that a phase error of 2π radians is created across the aperture the beam is widened to 3° half power beamwidth. Experience with this type of antenna indicates that a typical efficiency of 75% will be achieved, providing at least 45.9 dB gain at 95 GHz for the 1° beam.

This beam broadening effect is illustrated in Figure 3 and 4. Observe that the difference patterns are broadened too. The mechanical means of achieving correct focus (1° beam) and suitable defocus (3° beam) involves the use of a second smaller lens located in between the feed horn and the larger lens.

The two lens system for the narrow beam is optimized by optical ray tracing computer programs subject to the constraint the focal length of the front lens alone differ by the distance required for the 2π radian phase error. For unity F/D this distance would be approximately one wavelength. It is anticipated that a very good two lens system can be made with aspheric surfaces easily fabricated from dielectrics such as Rexolite 1422. For the wide pencil beam, the small lens is rotated out of position. The large lens alone will have a

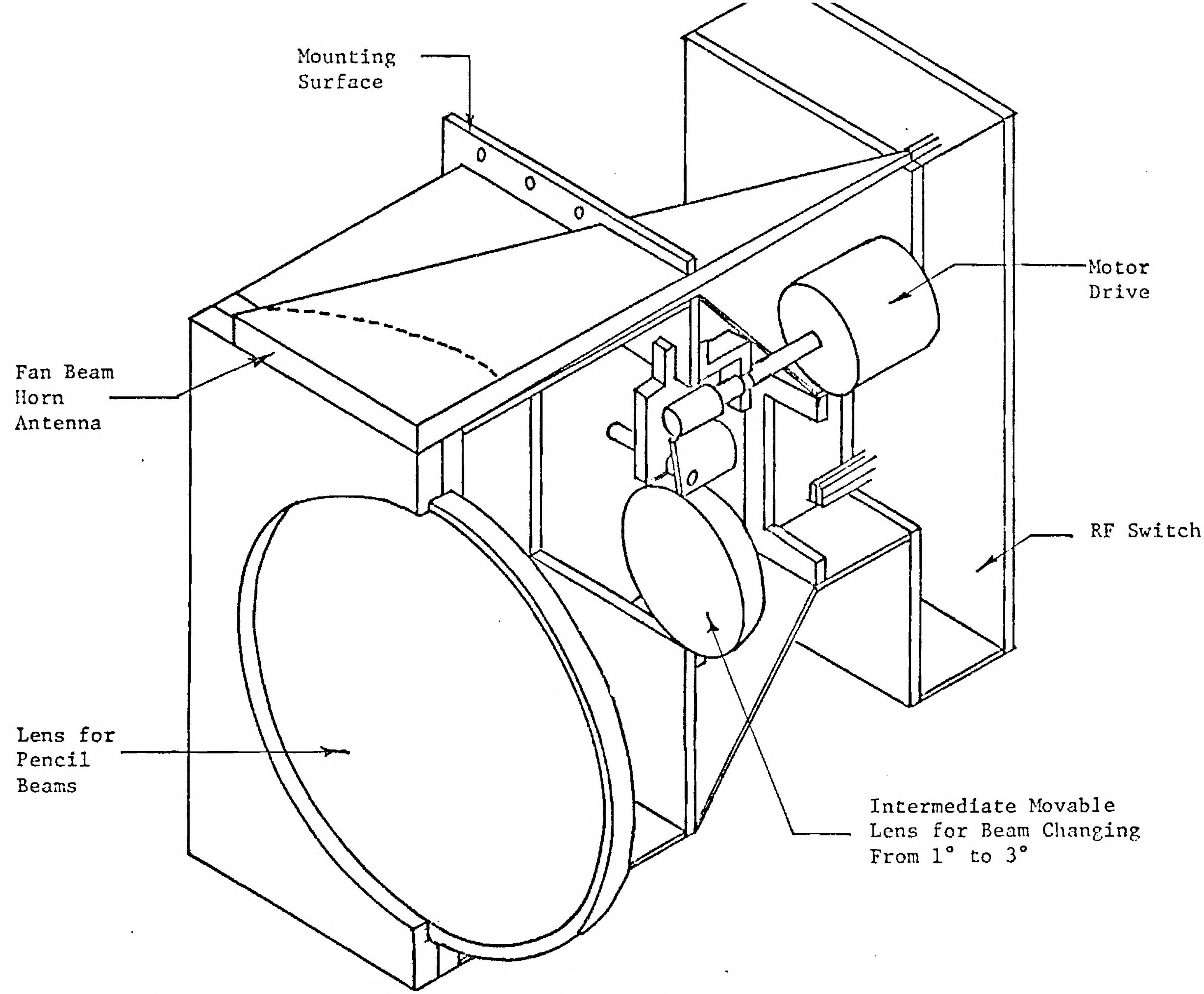


Figure 1. Multiple Beam 95 GHz Antenna Concept.

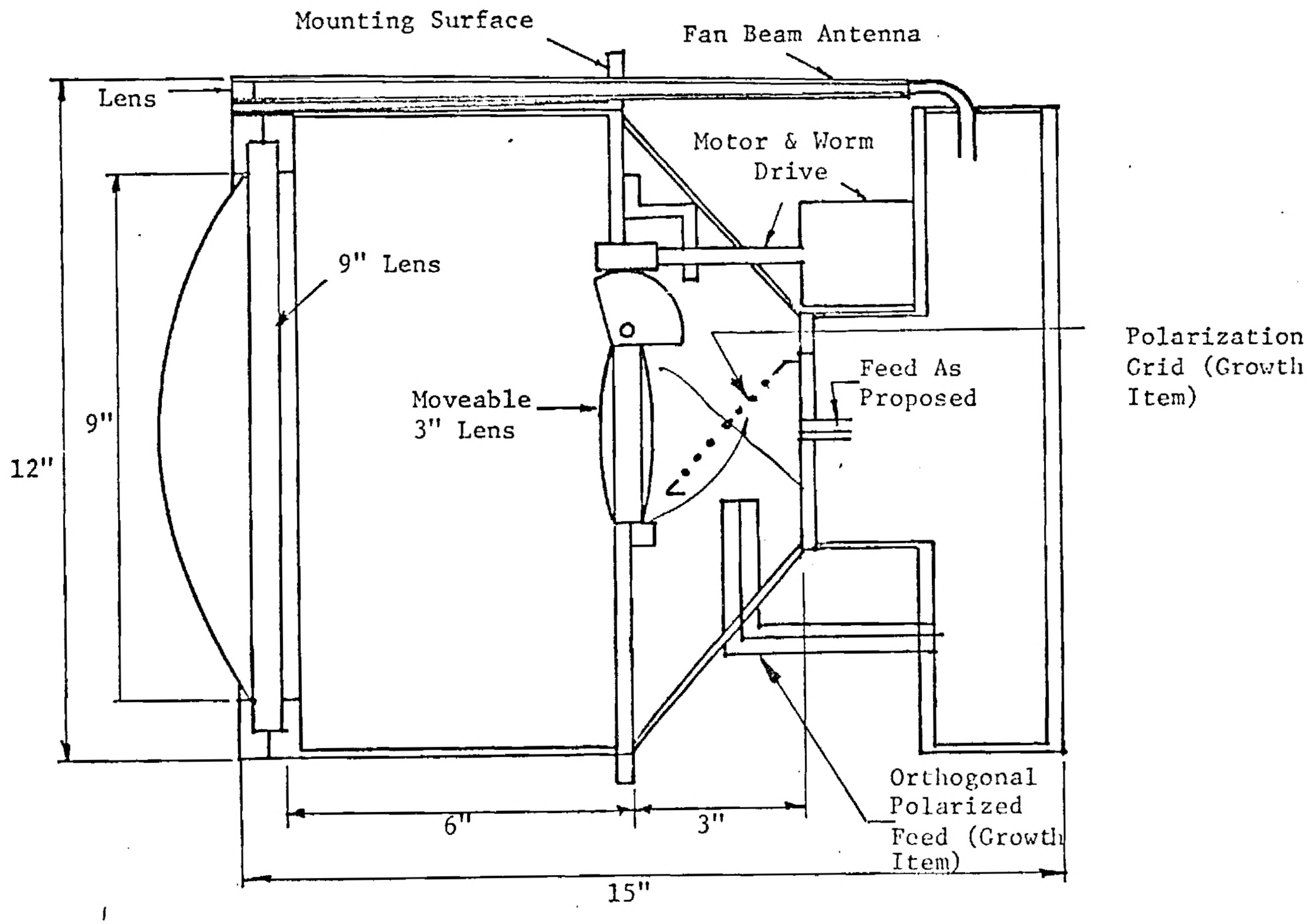


Figure 2. Side View of Antenna.

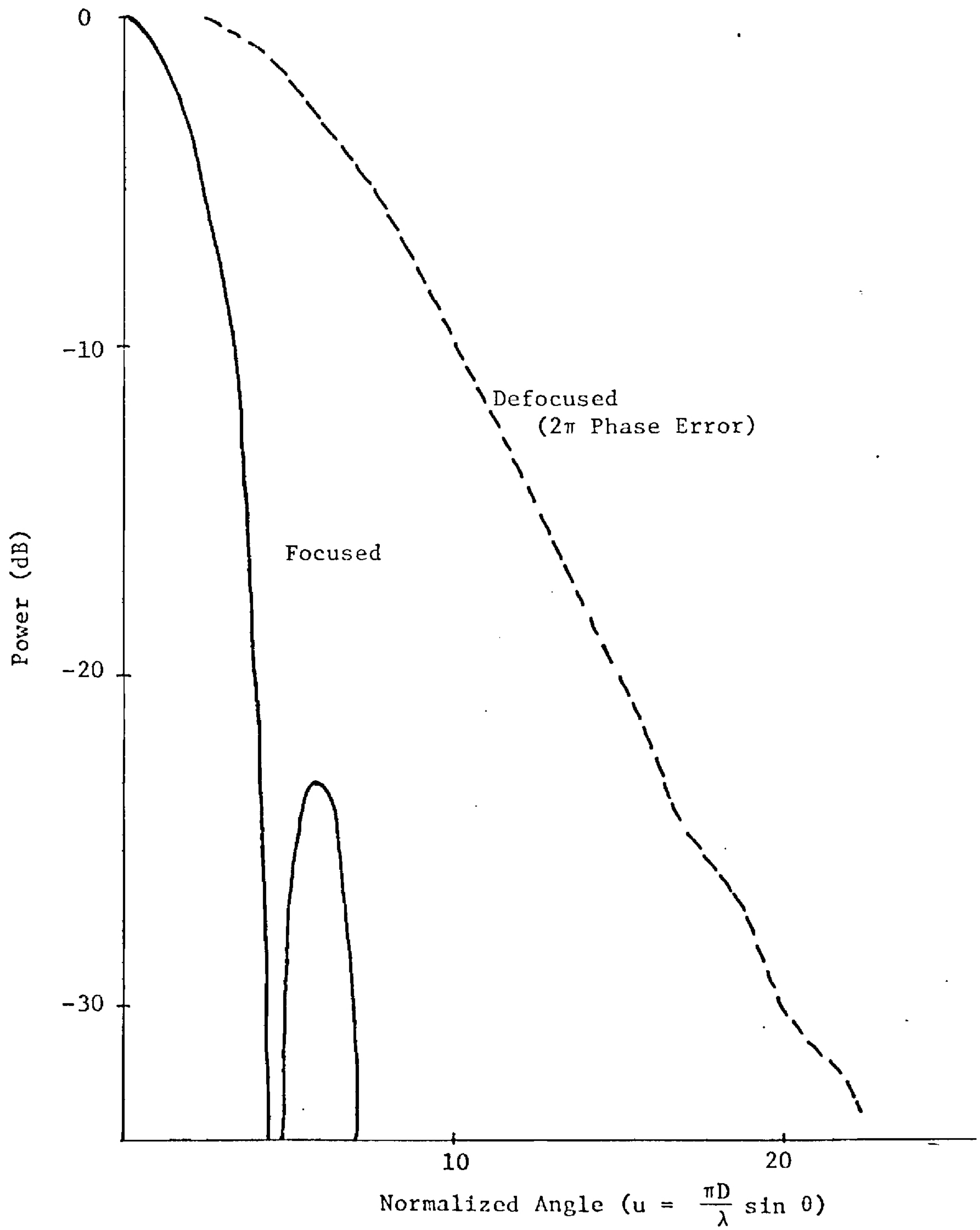


Figure 3. Sum Patterns (Focused and Defocused).

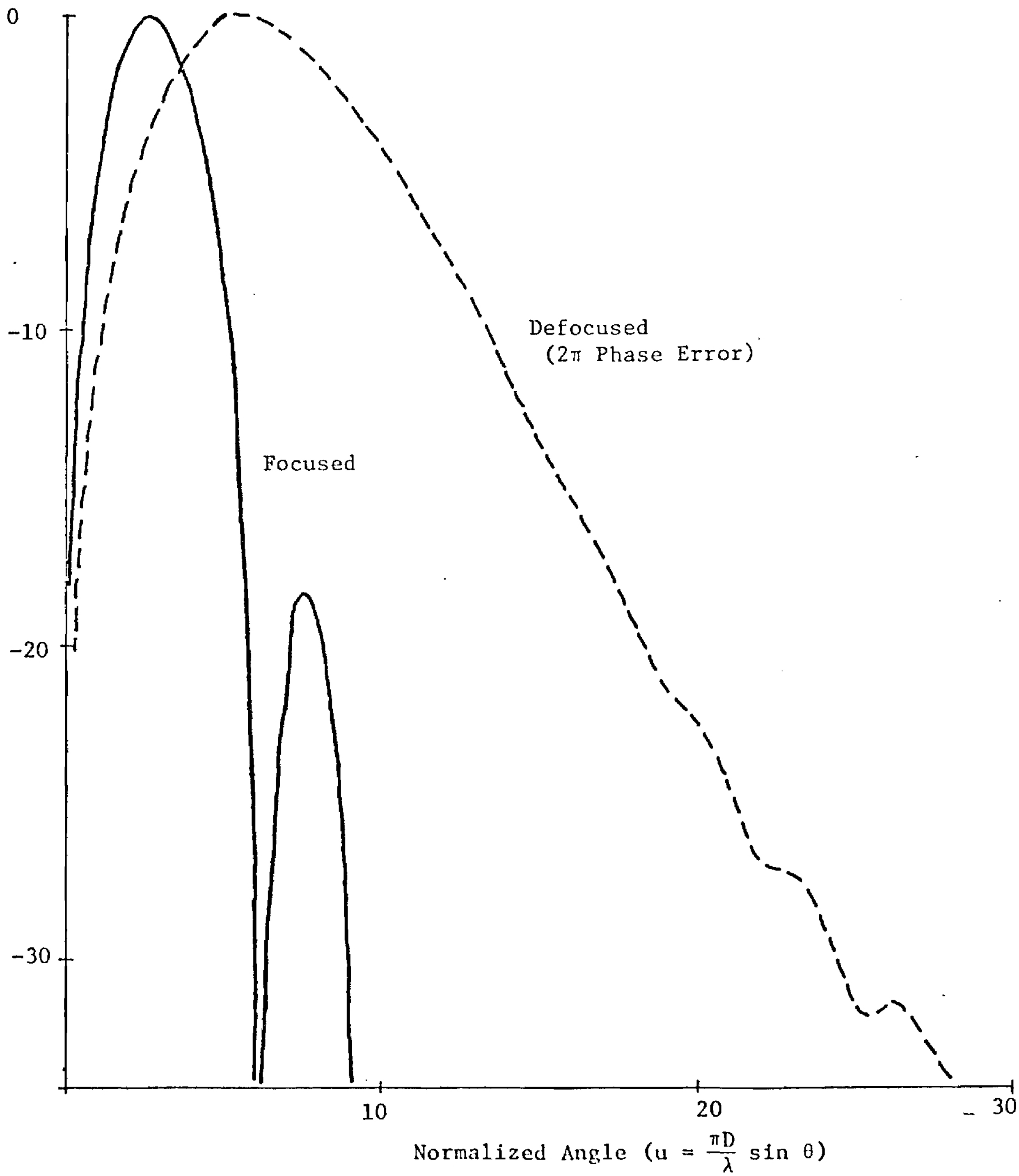


Figure 4. Difference Patterns (Focused and Defocused).

focal point which differs from the feed position by ΔF. An approximate expression for the maximum phase deviation (MPD) is known for the focal lengths of interest (Reference 1).

$$MPD = \frac{k\pi \Delta F/\lambda}{(F/D)^2}$$

where F = Focal length of lens element

D = Diameter of lens element

ΔF = Feed displacement from focus

λ = Wavelength

k = A constant determined by the type of aperture (lens or reflector)

This feed displacement yields a quadratic phase error for which Figure 4, 5 and 6 are applicable. Antenna patterns will be made to verify the lens system design.

This approach is very practical because only a small lens element needs to be moved and because there are essentially no RF loss elements involved in changing from 1° beam to the 3° beam. (The intermediate lens loss is estimated to less than 0.05 dB). The small lens element can be moved from one position to the other in less than one second, which when scaled by a factor of 1/30, simulates a change over speed of about 33msec, which is a reasonable time for that of a seeker system.

The feed proposed for this program is linearly polarized. Growth to dual polarization is possible with the antenna concept by the addition of a second similar, orthogonally polarized feed. Figure shows that through the use of a polarizing grid this second feed can share the same lens aperture.

The four feed elements are combined in a multi-hybrid comparator where the final RF ports are a sum, yaw difference, pitch difference and terminated port. The 180 degree waveguide hybrids can be either the magic-tee waveguide hybrid or the waveguide ring hybrid. Each type is adequate for this bandwidth. A model currently being fabricated utilizes ring hybrids, but a weight saving would be possible by using the magic-tee approach.

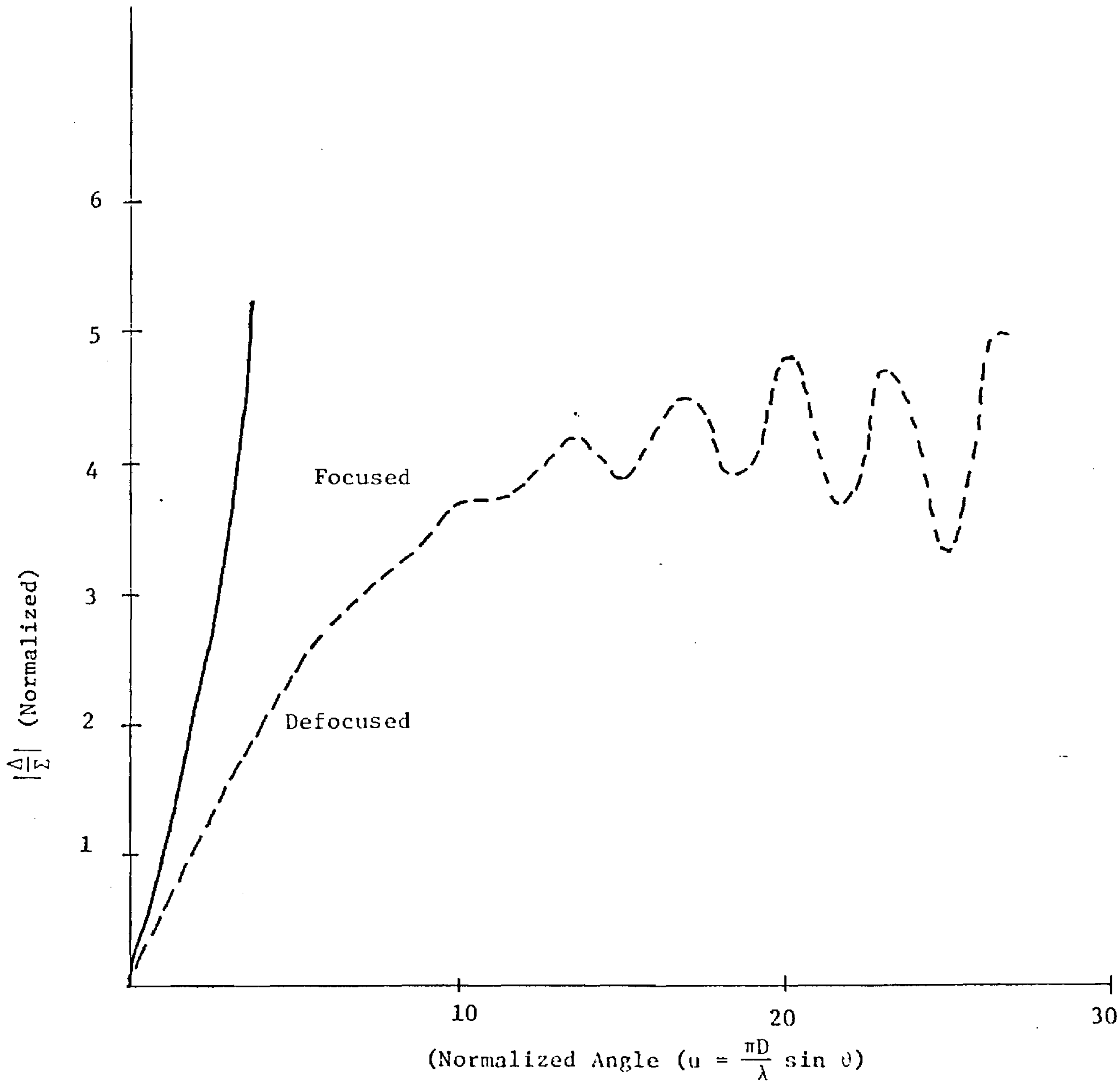


Figure 5. Angle Tracker Discriminator Curve (Focused and Defocused).

Fan Beam Element

To achieve the desired fan beam operation, a separate lens corrected sectorial horn antenna will be used. To achieve the desired 1° x 10° beam requires an aperture of about 9 inches by 0.8 inches. The lens in the aperture will correct the yaw plane phase error generated by the yaw plane flare over a length of approximately 9 inches. The horn will be further modified in the pitch plane to reduce the nominal 13 dB sidelobe to the required 20 dB. This aperture will be located immediately above the circular dual beam monopulse antenna. The output of the fan beam will be routed to a remotely controlled transfer switch which will allow the selection of either the fan beam or the sum beam (1° or 3° beamwidth). This transfer switch is the only RF switch proposed. Its RF loss is about 0.5 dB.

Mechanical Design

The mechanical concept of the antenna system is based on a rigid aluminum structure designed to withstand helicopter vibration environments and maintain the alignments of the antenna beams to better than 0.05 degrees.

The mechanical concept is shown in Figures 1 and 2. The outer housing for the 1° and 3° beams is an aluminum weldment with removable side plates. The alignment of the 9-inch lens, the 3-inch lens, and the monopulse feed elements is accomplished during the machining operations to within 0.004 inches. This constitutes a beam deviation of less than 0.03 degrees. When the two lenses are located in line in front of the monopulse feed the antenna beam is 1°. In order to switch from 1° beam to the 3° beam the 3-inch lens is rotated out of the viewing angle of the monopulse feed. The rotation of the 3-inch lens is accomplished by a small motor driving a worm gear located on one edge of the 3-inch lens mount. A positive detent type latch is provided when the lens is in the active position to prevent vibration of the lens during flight. This latch also provides the required alignment of the antenna beams. The fan beam antenna is a separate unit located on top of the pencil beam antenna housing. An adjustment mechanism is incorporated into the attachment points between the two antennas to allow alignment of the fan beam antenna to within 0.1° of the pencil beams. A separate compartment is located at the rear of the antenna assembly to house the WR-10 waveguide and various RF components associated with the radiometer and radar. The entire antenna assembly is attached to the gimbal by a mounting plate located approximately midway along the length of the overall assembly. The size of the assembly is 11 inches wide by 12 inches high by 15 inches long. The moment of inertia and center of gravity is shown in Figure 6.

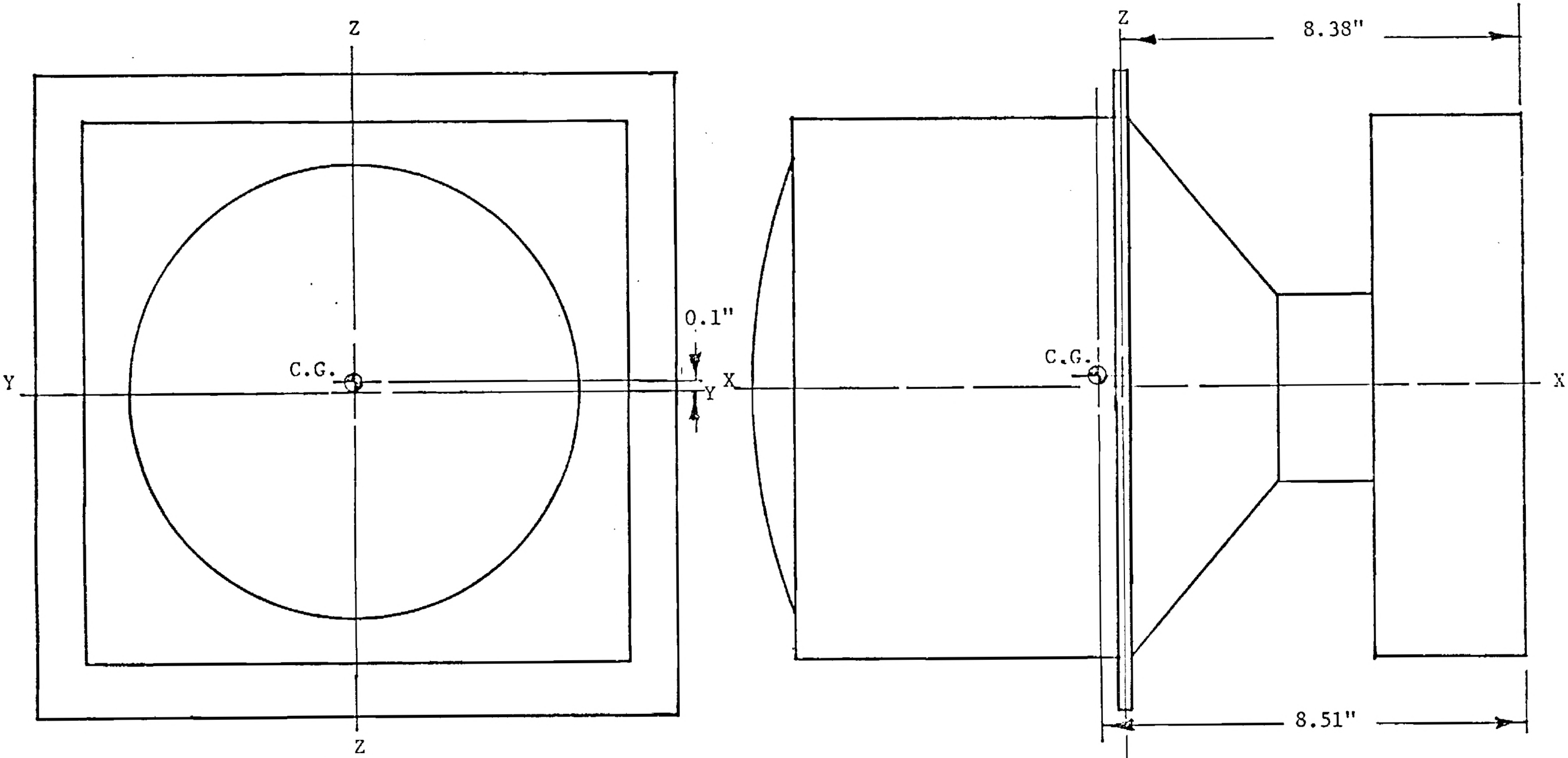
Weight Estimate

The overal calculated weight of the antenna assembly including the radiometer and radar RF components is 23.6 pounds. This is based on the weight breakdown given in Table I.

Block Diagram

The portion of the millimeter sensor to be developed by Georgia Tech is shown in Figure 7. Transmitter signals are routed to the pencil and fan beam ports of the antenna through a circulator and a computer controlled transfer switch. Received signals are routed through three ferrite switches to mixer downcoverters. The ferrite switches serve as Dicke switches when the sensor is used as a radiometer. The ferrite switch in the sum channel path also serves as a font-end protection switch when the sensor is used as a radar.

Following the Dicke switches are three low noise Schottky barrier diode mixers driven by a 94 GHz Gunn diode local oscillator. The Gunn oscillator supplies a nominal 20 milliwatts of power at its output and is thus capable of driving each mixer with 5 milliwatts of power. Immediately adjacent to each mixer is a low noise solid state IF preamplifier which provides a nominal gain of 20 dB.



$I_{xx} = 0.89 \text{ ft.}^2 - \text{lb.}$

$I_{yy} = I_{zz} \; 4.17 \text{ ft.}^2 - \text{lb.}$

Figure 6. Center of Gravity and Moment of Inertia.

TABLE I

ANTENNA WEIGHT BREAKDOWN

Aluminum Housings		12.8 pounds
Main Lens Housing	8.2 pounds	
Transition Housing	0.8 pounds	
RF Housing	3.8 pounds	
Lenses		4.7 pounds
Main Lens	4.3 pounds	
Fan Beam Antenna Lens	0.1 pounds	
Moveable Lens	0.3 pounds	
Motor Drive		0.8 pounds
Motor	0.5 pounds	
Drive Shaft, Worm & Worm Gear	0.1 pounds	
Brackets for Motor Drive	0.2 pounds	
RF Components		5.3 pounds
4 Rate Race Hybrids	1.5 pounds	
Waveguide, Wiring, Switches	0.5 pounds	
Fan Beam Antenna	0.5 pounds	
Transmitter, Oscillator, AFC	1.5 pounds	
Miscellaneous Hardware	0.5 pounds	
Mixer & Pre-amp	0.8 pounds	
	TOTAL	23.6 pounds

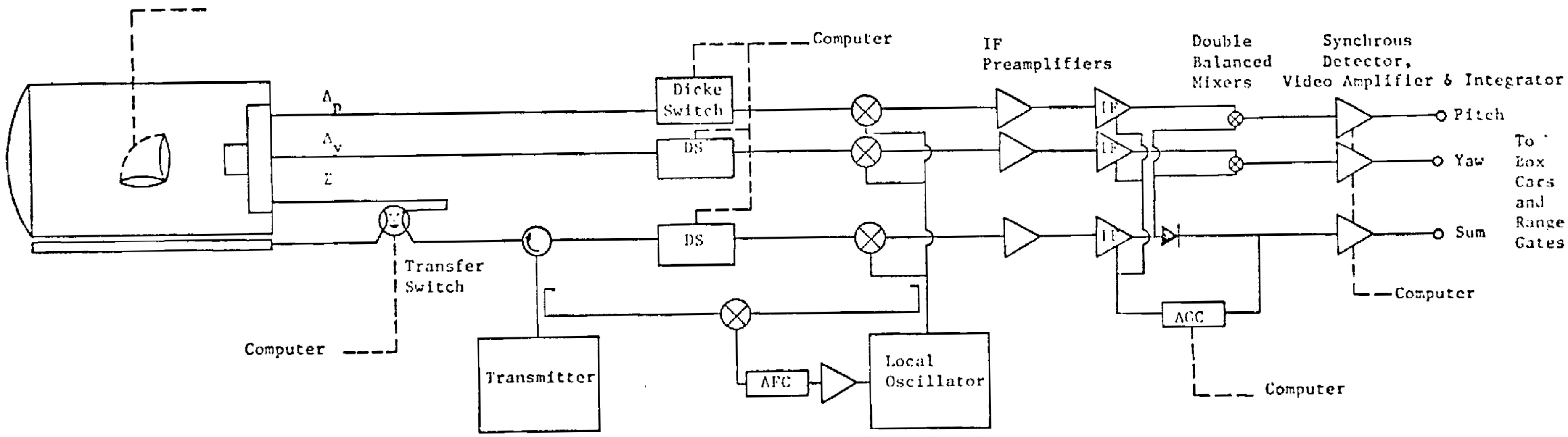


Figure 7. Millimeter Sensor Block Diagram.

Remotely located (off of the gimbal) are the receiver back components. Three high gain linear IF amplifiers are next in the signal path. These amplifiers have an AGC range of 40 dB necessary for both slow changes in signal level due to range and reflectivity changes and for faster monopulse signal normalization. Since the Δ channels are gain controlled by the sum channel, the IF output of the angle channels are Δ_p/Σ and Δ_y/Σ. The speed of the AGC is under the control of the computer and one can select how many pulses are to be averaged for this monopulse normalization.

Video detection is done differently in the sum channel than from the angle channels. Following the sum IF amplifier is a square law envelope detector. The output of the detector is used for normal radar video processing involving threshold detection and range gating. The sum video is also used in the AGC loop.

Video detection in the angle channels is performed by a double balanced mixer (DBM) (also called a phase sensitive detector). One input to each DBM is the sum channel IF which serves as a phase reference, the other input is the output of one of the difference channel IF's. In the vicinity of boresight the angle channel video amplitude out of the DBM is proportional to that of the difference channel. However, the video is bipolar and changes sign on either side of boresight due to the 180° phase change of the difference channel IF.

Following video detection each channel is fed to a video amplifier having several variable parameters under the control of the computer. In the radar mode of operation the video amplifiers function as wideband amplifiers for pulse fidelity. In the radiometer mode the video signals are fed to synchronous detectors to remove the Dicke modulation and then to low pass amplifiers serving as radiometer integrators.

Radiometric Sensitivity

The temperature that an antenna measures can in the general case be expressed by

$$T_a(\theta_o, \phi_o) = \frac{\int_{4\pi} T_{ap}(\theta,\phi)G(\theta,\phi)d\Omega}{\int_{4\pi} G(\theta,\phi)d\Omega}$$

where (θ_o, ϕ_o) is the direction of the observation cell from the antenna. This equation may be placed in the more conventional form by accounting for the mainbeam and sidelobe contributions separately and by including the characteristics of the antenna. When these modifications are made, the expression becomes

$$T_s(\theta_o,\phi_o) = n\alpha_m \overline{T}_{ap}(\theta_o,\phi_o) + n(1 - \alpha_m)\overline{T}_{se}(\theta_o,\phi_o) + (1 - n)T_o$$

where $\overline{T}_{se}(\theta_o,\phi_o)$ = the average temperture of the sidelobe regions

n = antenna radiation efficiency

α_m = mainbeam efficiency.

$\overline{T}_{ap}(\theta_o,\phi_o)$ = the average temperature of the mainbeam region

T_o = the antenna temperature.

Applying this equation to the sensitivity requirement contained in the RFI, it is found that the presence of the 1000°K-m^2 target will result in an increase of 33°K. These numbers are for an antenna that has the following characteristics:

3 dB Beamwidth	1°
Target Range	300 Meters
Mainbeam Efficiency (α_m)	0.95
Radiation Efficiency (n)	0.75
ΔTA_T	1000°K-m^2

The Dicke radiometer receiver has a minimum detectable temperature given by

$$\Delta T_{min} = \frac{2(F_n - 1)T_o}{\sqrt{\beta \cdot \tau}}$$

where F_n = System noise figure

β = System bandwidth

τ = System integration time

The proposed radiometer will have the following parameters

F_n = 14.85 dB (See Table II)

T_o = 290°K

β = 500 MHz

τ = 0.1 sec.

which gives the system a ΔT_{min} of 2.40°K. Defining the system signal to noise ratio to be

$$\frac{S}{N} = \frac{\Delta T}{\Delta T_{min}}$$

this receiver would then have a signal to noise ratio of 11.3 dB. Better performance can probably be achieved in the operational hardware by reducing the loses shown in Table II.

TABLE II

RF LOSS BUDGET

LOSS ITEMS	ANTENNA		
	1° Pencil	3° Pencil	Fan
Radome	0.1 dB	0.1 dB	0.1 dB
1st Lens	0.2 dB	0.2 dB	0.2 dB
Reflection Loss	0.23 dB	0.23 dB	0.0 dB
2nd Lens	0.05 dB	0.0 dB	0.0 dB
Spillover Loss	0.67 dB	0.67 dB	0.0 dB
Feed	0.30 dB	0.30 dB	1.0 dB
2nd Lens	0.05 dB	0.0 dB	0.0 dB
Feed	0.5 dB	0.5 dB	1.0 dB
W/G	0.8 dB	0.8 dB	0.8 dB
Hybrid Loss	1.0 dB	1.0 dB	0.0 dB
W/G	0.2 dB	0.2 dB	0.0 dB
Switch	0.5 dB	0.5 dB	0.5 dB
W/G	0.2 dB	0.2 dB	0.2 dB
Circulator	1.0 dB	1.0 dB	1.0 dB
W/G	0.2 dB	0.2 dB	0.2 dB
Dicke Switch	1.2 dB	1.2 dB	1.2 dB
W/G	0.2 dB	0.2 dB	0.2 dB
Mixer Conversion Loss*	6.5 dB	6.5 dB	6.5 dB
	13.35 dB	13.3 dB	11.9 dB

*Mixer Noise Figure = 8.0 dB (DSB)

Tolerance Budget for the Narrow Antenna Beam

The tolerance budget for the narrow pencil beam antennas is given in Table III. These are for individual errors alone. The precomparator phase errors are computed from equation A

$$\Delta\theta = \frac{\Delta u}{\pi D/\lambda} \qquad \text{(A)}$$

where D is lens diameter

λ is mean wavelength

Δu is electrical degrees of wavefront tilt

$\Delta\theta$ is spatial angular error near boresight.

This formula is equivalent to the beam shift caused by an electrical error of Δu to a 2-element interferometer with element spacing D/2.

A radome with a thickness gradient of +0.003" per 9" will yield an electrical wavefront phase error of 8.6 degrees per 9". Using the average phase error of 4.32 degrees in equation A, a boresight error of 0.019 degrees is obtained as listed in Table III.

The feed mechanical alignment refers to the feed horns illuminating the dielectric lens. If the centerline of the feed array is offset laterally to the direction of propagation by 0.003 inches, the beam shift is readily calculated from the arc tangent of this displacement over the focal length to yield a boresight error of +0.019 degrees. A longitudinal displacement (in direction of propagation) of one feed element relative to the other three feed elements yields an electrical error of 8.6 degrees relative to each of the other three elements. This gives an average electrical phase error of 4.32 degrees in the yaw plane and 4.32 degrees in the pitch plane. Each plane will have a spatial angular error of +0.019 degrees.

A tilt of the large lens with $f/D = 1$ would have no effect in the absense of lens aberrations. Aberrations in this lens system will be minimized by the use of aspheric surfaces.

The waveguide from the feeds to the first comparator hybrid has an effect on the boresight error similar to the feed longitudinal displacement effect. In addition, there exists an error from the tolerance for differential signal attenuation due to waveguide loss. In the presence of no other errors, this does not introduce an angular error at boresight. It does alter the slope of the error voltage. If one waveguide feed line is 0.25 dB low, each difference channel will be low by 1.4% and the sum channel by 0.7%. The net effect will be a decrease in the angular slope of 0.7% in the plane of the element containing the loss. In the orthogonal plane, the angular slope will be 0.7% higher.

The same analysis applies to the first hybrid of the comparator. In addition, imperfect isolation can contribute errors. In the case of 20 dB directivity adding in quadrature, the null depth will be degraded to 20 dB. An in-phase component of imperfect isolation of 20 dB will lead to a boresight error signal equal to $\Delta u = 0.1$. This corresponds to a spatial angular error of 0.025 degrees. The direct effects of VSWR have already been accounted for by the phase and amplitude specification.

The next waveguide section and the second comparator hybrid are treated in manner. After the second comparator hybrid the spatial imformation has been encoded differently. The 2.88° electrical phase error produces no spatial angular error but produces assymmetry in the phase detector. The electrical loss of 0.05 dB in a difference channel will produce a reduction in the difference channel of .57%. This is a linear reduction in the spatial angular slope.

Similarly, an 0.25 dB differential loss between the difference channel mixer and the sum channel mixer results in a 2.8% reduction in the spatial angular slope.

The LO distribution network has an effect on the angle detector outputs due to the possible introduction of insertion phase. The mixers will be driven at an LO level high enough above the signal level to prevent any significant departures from signal linearit Since the RF frequency band of operation is relatively narrow (1%), the error effects in the table can be corrected and minimized provided they can be detected and measured. The most sensitive indicator will be the actual antenna measurements and these will be used for the final alignment.

The final error which cannot readily be calibrated is due to thermal expansion of the long components, principally the waveguide. A temperature differential of 10°F in the symmetrical precomparator waveguide runs to the antenna feed will produce a length difference of +0.0005". This in turn yields a spatial angular error contribution of +0.003°.

TABLE III

TOLERANCE BUDGET FOR THE NARROW PENCIL BEAMS

COMPONENT ITEM	TOLERANCE	BORESIGHT ERROR, INDIVIDUAL CONTRIBUTION
Radome: Differential Thickness	+0.003"	+0.019°
Feed Mechanical Alignment:		
Transverse Center	+0.003"	+0.019°
Longitudinal Element	+0.003"	+0.019°
Large Lens (Aberration limited only for f/D=1)	+0.004"	+0.002°
Waveguide Differential:		
Length	+0.001"(+2.88°)	+0.006°
Loss	+0.05 dB	+0.7% Angular Slope
Hybrid Imbalance:		
Amplitude	+0.25 dB	+3.5% Angular Slope
Phase	10°	+0.022°
Isolation	20 dB	+0.022°
VSWR	1.25/1.0	Interaction Only
Waveguide Differential:		
Length	+0.001"(+2.8°)	+0.006°
Loss	+0.05 dB	+0.7% Angular Slope
Hybrid Imbalance:		
Amplitude	+0.25 dB	+3.5% Angular Slope
Phase	+10°	+0.022°
Isolation	20 dB	+0.025°
VSWR	1.25/1.0	Interaction Only
Waveguide Differential:		
Length	+0.001"(+2.88°)	Assymmetry
Loss	+0.05 dB	+0.7% Angular Slope
Mixer	+0.25 dB +10°	2.8% Angular Error Assymmetry
LO Distribution	+1.0 dB +10°	Negligible Effect Assymmetry
Thermal Heating Differential:		
5" Ag Precomparator Waveguide	+10°F	+0.003°

Radome for Sensor and Gimbal Assembly

The Instrumentations Sensor and the Associated flight hardware will be behind on optically clear radome which is attached to the bottom of the helicopter. The radome is formed from a spherical surface and mounted so that its center of curvature coincides with the gimbal pivot point as shown in Figure 8. This technique allows the optical and electrical performance characteristics to remain constant for all scan angles. The electrical and optical sensors will be mounted as shown in Figure 8.

It is presently planned to construct the radome from a plastic material, having a dielectric constant of about 2.5 and a loss tangent of approximately 0.002, using a multiple half-wavelength wall. For this construction a typical design might be as follows

Thickness: $$d = \frac{n\lambda_o}{2\sqrt{\varepsilon_r}} \quad \frac{(4)(0.1242)}{(2)(\sqrt{2.5})} = 0.157 \text{ inches}$$

Transmission Gain: $$T^2 = 1 - \frac{n\pi(\varepsilon_r + 1)\tan\delta}{2\sqrt{\varepsilon_r}} = 0.972(-0.12 \text{ dB})$$

Future Variations of the Instrumentation Sensor

One of the desired variations is the addition of a 35 GHz fan beam. For the 3° in azimuth by 10° in elevation coverage, a second lens-corrected pyramidal horn will be utilized. The horn will have the same width and length but will be approximately 3 times as deep. All new RF hardware must be added. A new local oscillator is required. Since monopulse operations is not requested for the 35 GHz channel only one RF channel is required. If simultaneous monopulse operation at 94 GHz is not required, one of the 94 GHz difference channel's IF and video hardware can be utilized.

A second angle processing mode for future addition is conical scan. This can be accomplished with a rotating dielectric wedge inserted between the lens and the feed as shown in Figure 9. Only the 94 GHz sum channel is required to be used for this angular mode. In addition a new video angle detector must be built.

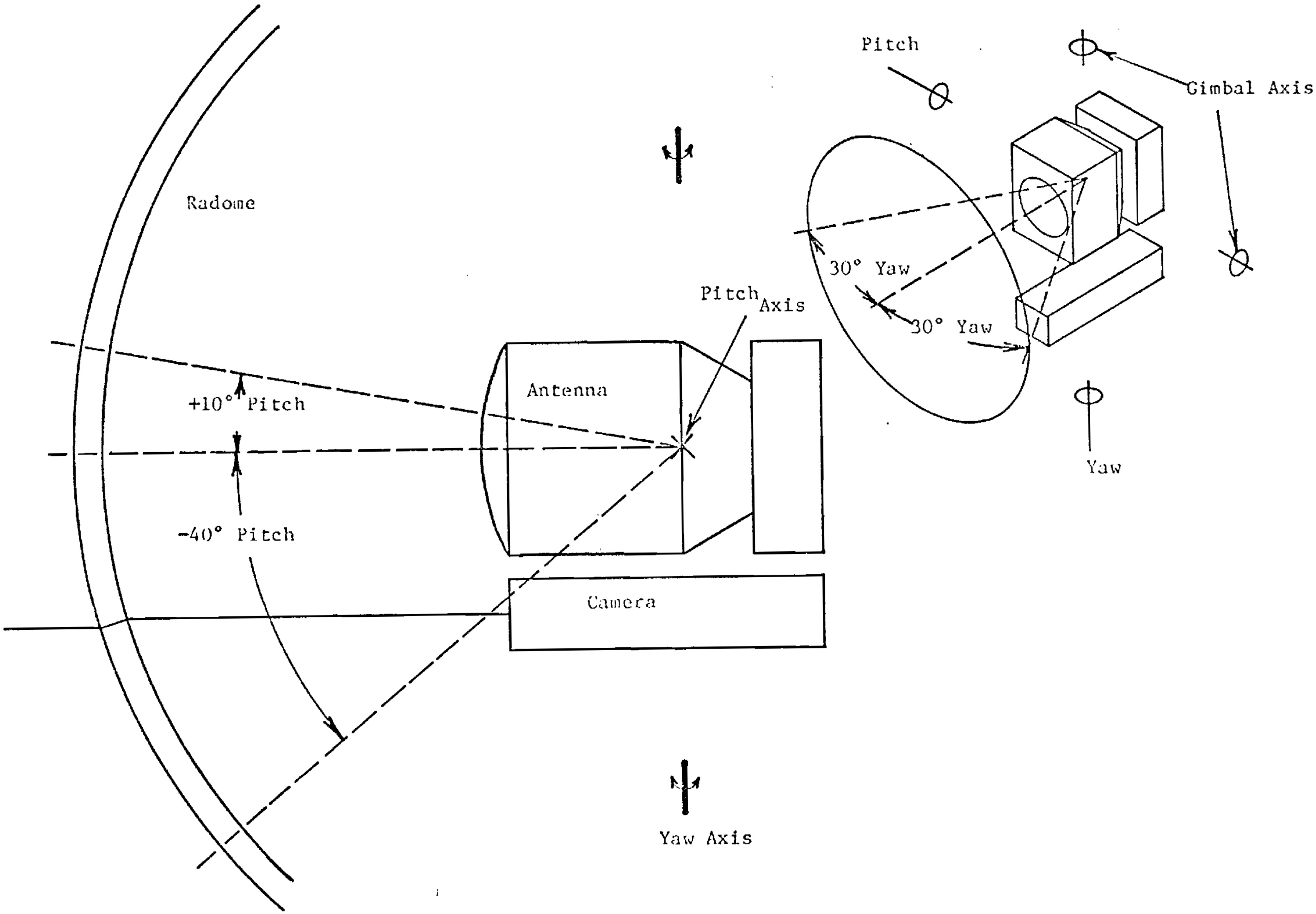


Figure 8. Radome Sensors Orientation.

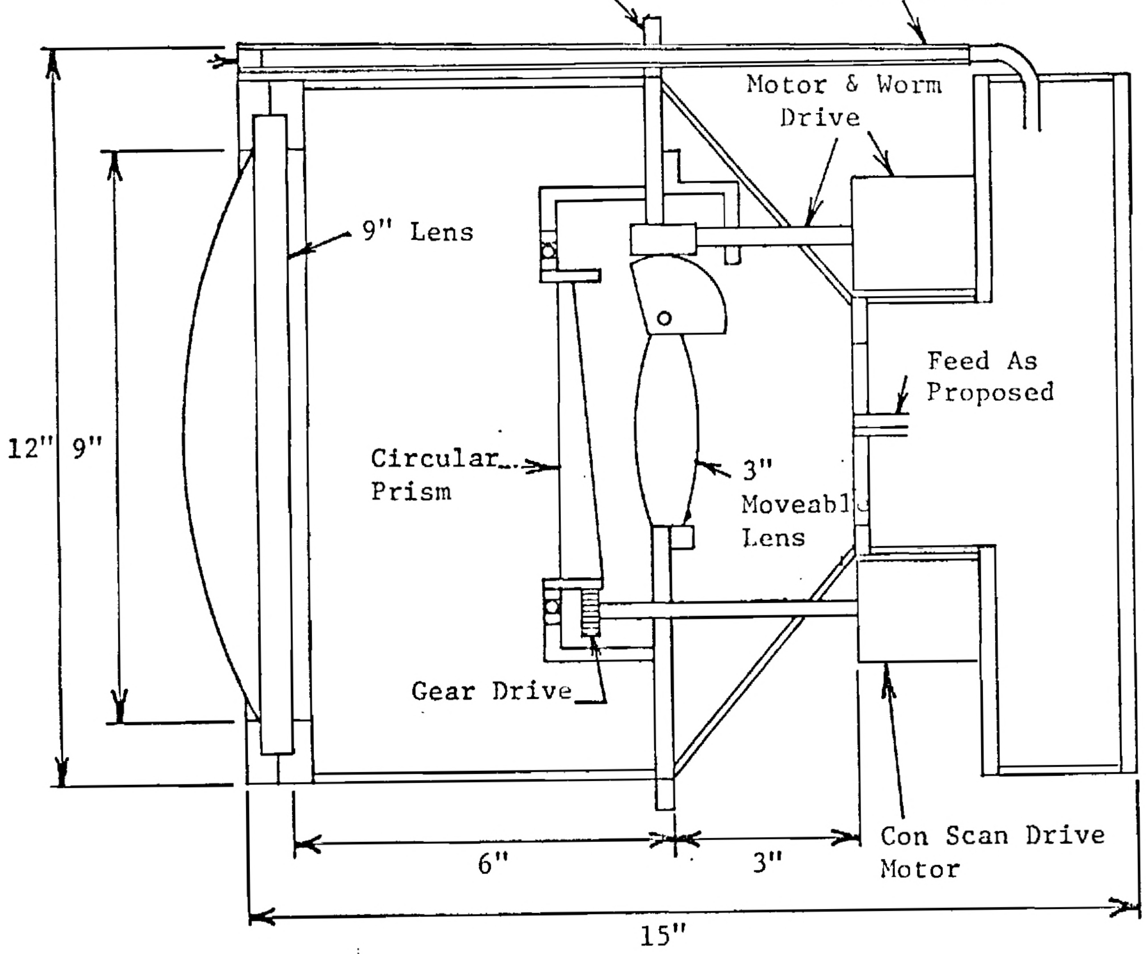


Figure 9. Side View of Antenna.

Tracking Performance of Narrow Pencil Beam

For the active mode the error sources which affect the angular accuracy arise from the following (Reference 2):

1. Tracking and data readout,
2. Antenna and receiver noise,
3. Uncertainties due to flexural and torsional misalignments of the antenna and
4. Stabilization data (pitch, roll, yaw) of inertial references which may be used on the platform.

Mean square angular errors converted to feet take the following form in terms of range, R, pitch angle, P, and yaw angle, Y.

$$\sigma^2 = \sigma_R^2 + R(\sigma_p^2 + \sigma_Y^2 \cos^2 p)$$

Each of the angle channels has the following root mean square angular error, σ_θ.

$$\sigma_\theta = \frac{\theta_B}{k_m \sqrt{\beta\tau (S/N)(f_r/\beta_n)}}$$

where

k_m = 1.4 = angle-error-detector slope

θ_m = 1° = antenna 3 dB beamwidth

S/N = 10 = signal-to-noise power ratio

β = 500 MHz = receiver bandwidth

β_n = 3 Hz = servo bandwidth

f_r = 30 Hz = pulse repetition frequency

τ = 100 ns = pulse width

For the assumed values the tracking error contribution from receiver noise can be expected to be approximately 0.01° for 10 dB S/N on the 1° pencil beam in the active mode.

In the radiometric mode, the expression is valid provided the S/N ratio concept can be properly determined for the particular scene.

Radiometer Calibration

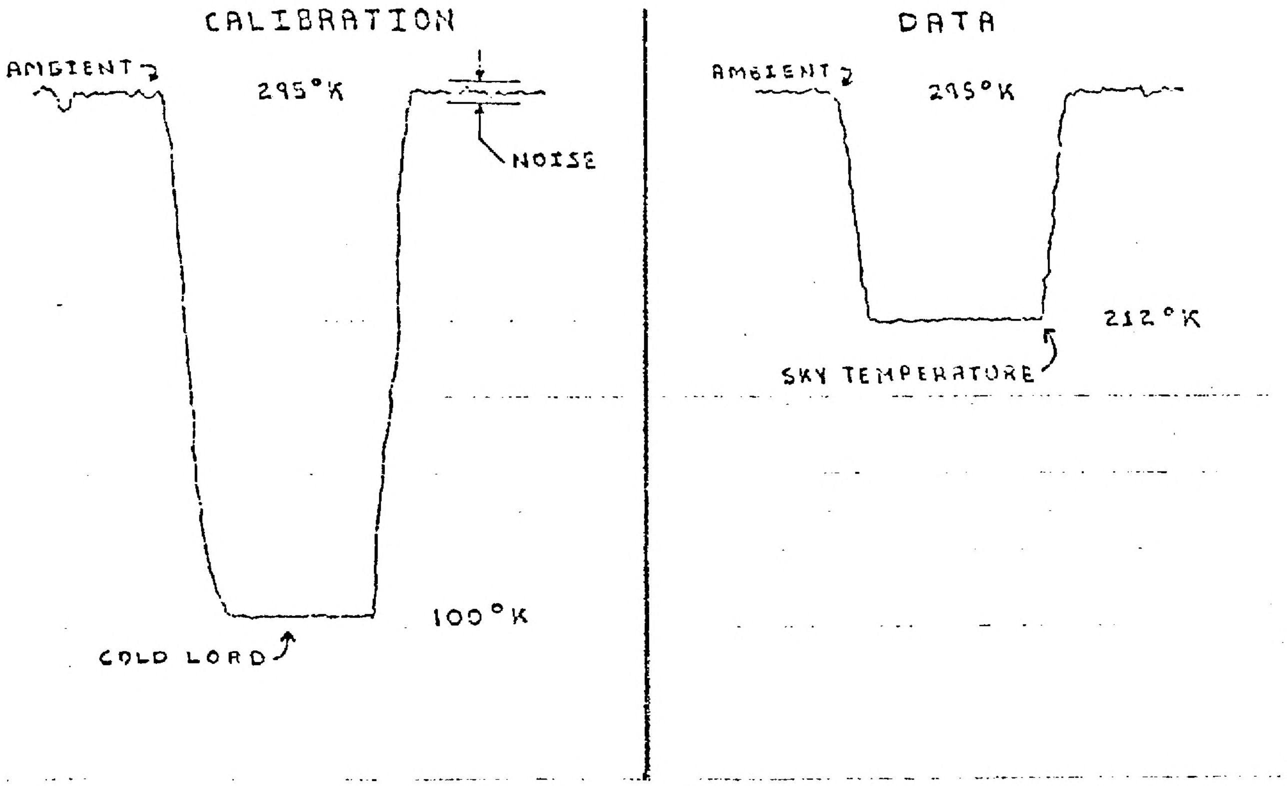
The two-temperature method* will be employed to calibrate the Instrumentation Sensor radiometer receiver. Two loads, having temperatures widely separated, will be alternately placed so as to intercept all of the main beam and sidelobe area of the antenna. The difference in the radiometer's output voltages will be used to establish the system's scale factor, the voltage change per unit temperature change.

The establishment of the minimum detectable temperature (ΔT_{min}) requires that the RMS value of the noise be measured while the higher temperature load is in front of the antenna. This may be done by measuring the peak-to-peak noise variations and dividing by 1.6. The ΔT_{min} can now be calculated from the following expression:

$$\Delta T_{min} = \text{RMS Noise x Scale Factor.}$$

A typical calibration chart is shown in Figure 10.

TYPICAL CALIBRATION AND DATA RECORD FOR
EACH FREQUENCY WHERE SKY EMISSIONS ARE MEASURED



~~BASIS~~
RADIOMETER CHARACTERIZATION

ΔT_{MIN} = NOISE (RMS VALUE) x SCALE FACTOR (°K/cm)

$$\Delta T_{MIN} = \frac{K(NF-1)\ T_o}{\sqrt{Bt}}$$ DOUBLE SIDEBAND SYSTEM

PARAMETERS		TYPICAL VALUES
K	DICKE CONSTANT	2.2
T_o	AMBIENT TEMPERATURE	295°K
B	IF BANDWIDTH	1.4 GHz
t	INTEGRATION CONSTANT	4.0 sec
ΔT_{MIN} . . .	MINIMUM DETECTABLE TEMPERATURE	0.9°K
NF	TOTAL SYSTEM NOISE FIGURE	20 dB

Figure 10. Typical Radiometer Calibration Chart.

References

1. Henry W. Redlien, "Monopulse Operation with Continuously Variable Beamwidth by Antenna Defocusing," Bell Telephone Laboratories Purchase Order 199355-23, September 20, 1961.

2. Constant, James, Introduction to Defense Radar Systems, Spertan Books, 1972.